In their discussion of near-infrared imaging of dental decay at 1310 nm (pages 8-16), Drs. Daniel Fried, Michal Staniniec, and Cynthia Darling comment upon the challenges of detecting and diagnosing carious lesions, especially in occlusal pits and fissures.

Over time, practitioners have utilized a variety of methods and technologies to detect carious activity in early stages of development, with the goal of helping to preserve the health of the dentition.

For example, in their review of advances in methods for diagnosing coronal lesions, Angman-Mansson and ten Bosch9 discuss endoscopic methods, fiber-optic transillumination (FOTI), light-scattering, laser fluorescence, ultraviolet illumination, penetration of dyes, iodide penetration, electrical resistance, ultrasonic imaging, and improved radiographic imaging techniques.

Goldstein and Parkins12 describe air abrasion as yet another method to diagnose pit and fissure carious lesions. Lundeen and Roberson11 enumerate three general categories of carious lesion detection methods, including (1) identification of subsurface demineralization through inspection, radiography, and dye uptake; (2) bacterial testing; and (3) assessment of environmental conditions such as pH, salivary flow, and salivary buffering.

Bader and colleagues3 analyze the effectiveness of visual, visual-tactile, radiographic, electrical conductance, FOTI, laser fluorescence, and combination methods to diagnose dental decay.

Shugars and Shugars2 identify several methods for diagnosing dental carious lesions: (1) visual changes in tooth surface texture or color, (2) tactile sensation when an explorer is used judiciously, (3) radiographs, and (4) transillumination. They also state “several new technologies have emerged that show promising results for the clinical diagnosis of caries” – laser-induced fluorescence, digital imaging fiberoptic transillumination (DIFOTI), quantitative light-induced fluorescence (QLF), and electrical conductance.

Readers of the Journal of Laser Dentistry will recall three recent articles on the topic of methods for carious lesion diagnosis:

- Otis, Zhu, and Ooi13 describe optical coherence tomography
- Hibst7 discusses fluorescence using a DIAGNOdent® (which utilizes a 655-nm diode laser)
- Karlsson and Tranæus8 consider fiber-optic transillumination, digital imaging fiber-optic transillumination, laser fluorescence, quantitative light-induced fluorescence, electronic caries measurement (ECM), and alternating current impedance spectroscopy.

Of historical interest is the role played by lasers in carious lesion diagnosis, most prominently in laser-induced fluorescence. (Fluorescence may be defined as the property of emitting light while exposed to light, with the wavelength of the emitted light being slightly longer than that of the light absorbed.)

By way of background, the phenomenon of fluorescence was first reported by Irish mathematician and physicist Sir George Gabriel Stokes10 in 1852. Hans Stübel15 reported in 1911 that tissue fluorescence could potentially be used for diagnostic purposes. In 1926 E. Newton Harvey noted: “Perhaps the fluorescence of the lens of the eye is best known, but most skeletal and supporting tissues such as bone, teeth, cartilage, nails, skin, tendon, etc., are markedly fluorescent and ordinary protein rich cells less so.”11 Notable researchers in the study of fluorescence of teeth include Benedict12 (1928) and Hartles13 (1953).

As indicated below, among the first to report on a laser luminescence method for cavity detection were Bjelkhagen and Sundström in 1981, using a 488-nm argon ion laser, and Sundström and colleagues in 1985, using an argon-ion laser at 488 and 515 nm, a nitrogen laser at 337 nm, and a helium-neon laser at 633 nm.

The appeal of using the blue-green argon laser wavelengths for cavity detection is described by Manni: “Teeth fluoresce at yellow, orange, and red wavelengths in response to transillumination with blue-green argon wavelengths. [The lesions] appear as dark areas against a fluorescent background, and tend to be orange-red in color. Decalcified areas appear as dull orange-colored areas.”14

Other researchers have investigated the possible role other laser wavelengths (including 442-nm HeCd15 and 407-nm krypton ion,16 for example) in cavity-detecting via laser-induced fluorescence of enamel.

Additional laser wavelengths have been studied as possible methods to diagnose carious lesions, apart from fluorescence. In 1988, Benedetto and Antonson examined the in vitro use of a carbon dioxide laser to detect enamel fissure defects through the tracing of black carbonized zones of carious lesions. Longbottom and Pitts followed up with their own similar in vitro CO₂ laser study in 1993.
In 1994, Niemz reported how analysis of the spectra of plasma sparks induced by a picosecond 1053-nm Nd:YLF laser beam directed toward extracted human molars may provide more detailed information than fluorescence. He suggests the possibility of computer-controlled lesion removal by a laser-based automated system.

Such laser-related studies demonstrate the ongoing pursuit of a reliable means of detecting and diagnosing dental decay, much as Fried and colleagues illustrate in their work with near-infrared imaging.

As always, clinicians are advised to review the specific indications for use of their lasers and to review their operator manuals for guidance on operating parameters before attempting similar techniques on their patients.

REFERENCES

LASER-INDUCED FLUORESCENCE FROM SOUND AND CARIOUS TOOTH SUBSTANCE: SPECTROSCOPIC STUDIES

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Fluorescence spectra of dentine and enamel illuminated with laser light of wavelengths of 337, 488, 515, and 633 nm respectively were recorded. The fluorescence obtained by illumination with ultraviolet laser light at 337 nm had a peak at about 400 nm in dentine as well as enamel. Compared to intact enamel the fluorescence from enamel with initial carious lesions was of lower intensity and had a slight red shift. No fluorescence within the visible range was obtained by illumination with a low power He-Ne laser at 633 nm. Illumination at 488 nm produced fluorescence with a peak at about 540 nm in dentine as well as enamel.

The difference in the intensity of fluorescence between sound and carious enamel was generally greater at this wavelength than at any of the others tried, and the red shift from the carious enamel was also more pronounced. Illumination at 515 nm produced fluorescence of similar wavelengths but with much less difference between intact and carious enamel. It was concluded that illumination at 488 nm was the most suitable wavelength of those investigated for the detection of initial carious lesions by the fluorescence technique.

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A CLINICALLY APPLICABLE LASER LUMINESCENCE METHOD FOR THE EARLY DETECTION OF DENTAL CARIES

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It is well-known that dental enamel and dentine luminesce when excited by light in the ultraviolet and short-wave visible range and that this luminescence is different in intact and carious tooth substance. This effect has been proposed as a means for detection early enamel caries, but the methods applied have generally involved extensive protective measures against ultraviolet radiation and complicated detection stems. A method has been developed where the teeth are illuminated by laser light from an argon-ion laser in the blue region (i.e., 488 nm) and observed directly or photographed through a barrier filter. The filter transmits light of wavelengths greater than about 540 nm and serves as a convenient isolator separating luminescence occurring at longer wavelengths from the tooth-scattered laser light at 488 nm. Incipient carious lesions in the enamel are visible as dark spots before they can be observed in ordinary light or by the ultraviolet method mentioned earlier. Even initial pit and fissure lesions are clearly visible. To investigate the capabilities of the method, human teeth—intact and with carious lesions of different sizes—have been studied. The appearance of the laser-illuminated teeth has been photographed using the same type of filter as for direct observation in front of an ordinary camera. The presence of caries at the observation sites has been confirmed using microradiography and polarizing microscopy. The technique can also be used in monitoring the elimination of carious enamel and dentine from larger carious lesions and as an aid to rapid and reliable scoring of experimental caries in animals. The technique seems to be a simple and convenient tool for early detection of human caries in clinical situations.

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USE OF CO2 LASER FOR VISIBLE DETECTION OF ENAMEL FISSURE CARIES

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One of the most subjective clinical responsibilities a dentist faces is the determination of the presence of occlusal fissure caries using an explorer. The objective of this study was to investigate whether a carbon dioxide laser might be able to detect occlusal caries and whether its use might be more objective and reliable than conventional methods. Fifty recently extracted human molars and premolars were selected for this study. Thirty-four teeth were diagnosed as having occlusal caries, while the remaining 16 teeth were diagnosed as having no occlusal caries. Diagnosis was determined by sharp explorer analysis. All teeth were examined by the same diagnostician. Diagnosed areas of caries were marked on the occlusal tracings. Care was taken to mark as accurately as possible the exact location of the caries detected. Next, the teeth were exposed to a CO2 laser (Pfizer Laser Systems) at 2.5 W of power at 18 pulses per second with a 500-µm spot size. The lased teeth were then compared with the explorer-examined teeth to determine whether any relationship existed between the two groups and to determine which diagnostic regime resulted in more caries being detected. When the teeth were examined after lasing, the occlusal surfaces appeared frosty (similar to an enamel occlusal surface after etching, rinsing, and drying). However, in some of the fissure areas, black zones were noticed. It is our opinion that these black zones were areas where demineralization had been present, leaving a higher organic compositional zone (with a higher water content) in the enamel. The 10.6-µm wavelength energy from the laser selectively altered these organic zones, causing a black carbonized residue. The black zones of the lased teeth were then mapped on tracings, magnified X 6, as was done for the explorer-determined caries zones. The explorer mappings and the lased mappings were then compared. Of the 16 teeth diagnosed by explorer as being noncarious before lasing, 4 had sufficient black zones after lasing to be labeled carious. Further, of the 34 teeth originally diagnosed by explorer before lasing as having enamel occlusal caries, 11 of these did not demonstrate black carbonized zones after lasing and therefore were labeled as noncarious. In traditional caries detection it is difficult to differentiate between a deep parallel-walled fissure, which by friction causes the explorer to “stick,” and one that is actually carious. A laser diagnosis, however, can make this differentiation and therefore identify the carious zone from the noncarious zone. In general, the observations made from this study seem to show that laser caries detection is more conservative than explorer detection and therefore might save patients unnecessary restoration.

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The diagnosis of small lesions in pit and fissure sites is becoming increasingly problematical. This study was designed to evaluate, in vitro, the potential use of a carbon dioxide (CO\textsubscript{2}) laser technique as an aid to the diagnosis of incipient pit and fissure caries. Vaporization of the organic material in the 'early' carious lesion should lead to its carbonization and thus make it more conspicuous. Pilot studies were carried out to identify lasing parameters which produced no visible effect on sound enamel but which caused char-ring (carbonization) of white spot fissure lesions. Fifty extracted human molars and premolars were air-polished on the occlusal surfaces and independently scored clinically for caries, both before and after lasing. The teeth were subsequently sectioned and examined histologically. Of the 37 sites histologically scored as sound or exhibiting precavitation lesions, eight were correctly scored as sound both prelasing and postlasing. Of the 29 precavitation lesions detected histologically, five were detected clinically prelasing and 11 were detected postlasing. This 21\% difference in the sensitivity of caries diagnosis between the prelasing and postlasing examinations was statistically significant (at the 95\% level). There were no false-positive caries diagnoses. Further research, in particular the refining of lasing parameters employed, is indicated.

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Diagnosis of caries by spectral analysis of laser-induced plasma sparks

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Detection of carious substance by luminescence has always been a challenge in dentistry. Parallel to the progress made in laser physics also new techniques for the diagnosis of caries were developed. The main method focuses on the detection of laser-induced autofluorescence after UV or visible irradiation. It is shown in the present paper, that spectral analysis of plasma sparks induced by a picosecond Nd:YLF laser system enables diagnosis of caries as well. This method is a completely different approach, since the information obtained from the ionized plasma itself is more detailed than available in fluorescence. A picosecond Nd:YLF laser system (1053 nm) was used to remove sound and carious enamel from extracted human sound molars by the mechanism of plasma-induced ablation. The plasma spark was optically imaged onto the entrance pupil of a spectrometer. The spectra were scanned between 400-700 nm with a typical resolution of 0.2 nm. Calcium in neutral and singly ionized states and the sodium doublet at 589 nm were observed. The second harmonic of the laser wavelength was generated in an external BBO (Beta Barium Borate) crystal, thereby converting about 10 \mu J of the pulse energy to radiation at 527 nm. The amplitude of the diffuse reflected second harmonic was used as a reference signal for normalization of the spectra. Several sound and artificial caries regions of different teeth were investigated. The spectra obtained from caries always showed a strong decrease in amplitude of all mineral lines, if compared to sound enamel. These results can be explained by the demineralization process of dental decay. Thus, caries infected teeth are easily distinguished from sound probes, enabling a computer controlled caries removal in the near future. The possible setup of such an automated system is discussed.

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